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SERVICE REPORT

RESEARCH MEMORANDUM

for the

Bureau of Aeronautics, Department of the Navy

FREE-SPINNING-TUNNEL INVESTIGATION OF A 1/28-SCALE MODEL OF THE NORTH AMERICAN FJ-4 AIRPLANE

TED NO. NACA AD-3112

By Frederick M. Healy

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Langley Field, Va.

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'IONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON
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SUMMARY

An investigation has been made in the Langley 20-foot free-spinning tunnel to determine the erect and inverted spin and recovery characteristics of a 1/28-scale dynamic model of the North American FJ-4 airplane.

The model results indicate that either a flat-type or a steep-type spin may be obtained when the airplane is spinning erect. Use of the optimum recovery technique, full rudder reversal accompanied by simultaneous movement of the ailerons to full with the spin, will provide satisfactory recoveries from the steeper of these types of spin for all mass distributions. For some conditions of mass distribution, however, this technique may not always insure recovery from the flat-type spin.

The optimum recovery technique from inverted spins was indicated to be full rudder reversal accompanied by simultaneous movement of the ailerons to full with the spin with the stick maintained full forward. Satisfactory recoveries should be obtained for all mass distributions by use of this technique.

Deflecting the leading-edge flaps or extending the speed brakes would have little effect on erect spins and recoveries. Satisfactory recoveries from emergencies encountered during spin-demonstration flights should be obtained by firing wing-tip rockets providing an antispin yawing moment of 20,000 foot-pounds or by opening a parachute of 15.2-foot diameter (laid-out-flat) with a drag coefficient of 0.67, shroud lines 20.5 feet long, and attached to the airplane tail with a 39-foot towline. Tests of model rockets providing an equivalent prospin rolling moment of 60,000 foot-pounds also indicated satisfactory recoveries.

INTRODUCTION

At the request of the Bureau of Aeronautics, Department of the Navy, an investigation has been made of a 1/28-scale model of the North American FJ-4 airplane in the Langley 20-foot free-spinning tunnel. The FJ-4 airplane is a jet-propelled, low swept-wing, single-seat fighter airplane.

The erect spin and recovery characteristics of the model were determined for the basic design combat gross-weight condition (60 percent wing fuel), for this loading with all wing fuel removed, and for a loading indicated as representing a revised combat gross-weight condition (80 percent wing fuel plus spin-recovery rockets). In addition, the effect of deflecting leading-edge flaps or extending speed brakes on erect spins in the basic design combat gross-weight condition was investigated. Inverted spin and recovery characteristics of the model were determined for the revised design combat gross-weight condition, for an accident-test loading which simulated the loading of an airplane which crashed during the full-scale flight test program, and for this latter loading with emergency wing-tip spin-recovery rockets added. The size of spin-recovery tail parachute necessary to insure satisfactory spin recovery was determined, and the effect of firing wing-tip rockets during spins was investigated.

General descriptions of model-testing techniques, methods of interpreting test results, and correlation between model and airplane results are presented in reference 1.

SYMBOLS

b	wing span, ft
$\bar{c}$	mean aerodynamic chord, ft
C_n	yawing-moment coefficient, $\frac{\text{Yawing moment}}{qS}$
I_X,I_Y,I_Z	moments of inertia about X, Y, and Z body axes, respectively, slug-ft^2
$\frac{I_X - I_Y}{mb^2}$	inertia yawing-moment parameter
$\frac{I_Y - I_Z}{mb^2}$	inertia rolling-moment parameter

[redacted]

$\frac{I_Z - I_X}{mb^2}$ inertia pitching-moment parameter

m mass of airplane, slugs

q dynamic pressure, $\frac{1}{2}\rho V^2$

S wing area, sq ft

V full-scale true rate of descent, ft/sec

$x/\bar{c}$ ratio of distance of center of gravity rearward of leading edge of mean aerodynamic chord to mean aerodynamic chord

$z/\bar{c}$ ratio of distance between center of gravity and fuselage reference line to mean aerodynamic chord (positive when center of gravity is below line)

α angle between fuselage reference line and vertical (approximately equal to absolute value of angle of attack at plane of symmetry), deg

μ relative density of airplane, $\frac{m}{\rho Sb}$

ρ air density, slug/cu ft

ϕ angle between span axis and horizontal, deg

Ω full-scale angular velocity about spin axis, rps

MODEL

The 1/28-scale model of the North American FJ-4 airplane was furnished by the Bureau of Aeronautics, Department of the Navy, and was prepared for testing by the Langley Aeronautical Laboratory of the National Advisory Committee for Aeronautics. A three-view drawing of the model as tested is shown in figure 1.

The longitudinal control system of the FJ-4 includes both a controllable horizontal stabilizer and elevators. According to information received from North American Aviation, Inc., the elevators remain undeflected until the stabilizer reaches 4° leading edge down and at the maximum stabilizer deflection of 14° leading edge down the elevators are at 15° trailing edge up (relative to the stabilizer). The rate of deflection of the elevators with respect to the deflection rate of the stabilizer is approximately linear. The dimensional characteristics of the airplane are presented in table I. A photograph of the model is shown in figure 2.

The model was ballasted to obtain dynamic similarity to the airplane at an altitude of 30,000 feet ($\rho = 0.000889$ slug/cu ft). The mass characteristics for the loadings of the airplane and for the loadings tested on the model are presented in table II. A remote-control mechanism was installed in the model to actuate the controls for the recovery attempts. Sufficient torque was exerted on the controls for the recovery attempts to reverse them fully and rapidly.

The normal maximum control deflections used on the model during the tests (measured perpendicular to the hinge lines) were:

Rudder, deg	27.5 right, 27.5 left
Elevator, deg (with respect to horizontal tail)	15 up
Horizontal tail, deg	14 leading edge down, 6 leading edge up
Ailerons, deg	20 up, 15 down

All tests were made with speed brakes retracted and leading-edge flaps undeflected, except as indicated. Model rockets were installed only for the tests in which they were actually fired. For other tests equivalent weights were substituted.

MODEL ROCKETS

The model rockets used in this investigation were designed and developed by the Model Propulsion Section of the Langley Pilotless Aircraft Research Division. The rockets are precision built of steel and produce 3 ounces of thrust for 2 seconds. Based on the simulated test altitude (30,000 feet) and scale of the model used in the present investigation, the thrust of this rocket is equivalent to 1,539 pounds of thrust full-scale and the corresponding full-scale thrust duration is approximately 11 seconds. A more detailed description of this rocket is given in reference 2.

PRECISION

Results determined in free-spinning tunnel tests are believed to be true values given by models within the following limits:

α, deg . . . . ±1
ϕ, deg . . . . ±1
V, percent . . . . ±5
Ω, percent . . . . ±2
Turns for recovery obtained from motion-picture records . . . . . . $\pm\frac{1}{4}$
Turns for recovery obtained visually . . . . $\pm\frac{1}{2}$

The preceding limits may be exceeded for certain spins in which it is difficult to control the model in the tunnel because of the high rate of descent or because of the wandering or oscillatory nature of the spin.

The accuracy of measuring the weight and mass distribution of models is believed to be within the following limits:

Weight, percent . . . . ±1
Center-of-gravity location, percent $\bar{c}$ . . . . ±1
Moments of inertia, percent . . . . ±5

Controls are set with an accuracy of $\pm 1^{\circ}$.

Because it is impracticable to ballast models exactly and because of inadvertent damage to models during tests, the measured weight and mass distribution of the FJ-4 model varied from the true scaled-down values within the following limits:

Weight, percent . . . . 1 low to 12 high

Center-of-gravity location, percent $\bar{c}$ . . . . 1 forward to 2 rearward

Moments of inertia:
I_X, percent . . . . 8 low to 1 high
I_Y, percent . . . . 1 low to 11 high
I_Z, percent . . . . 2 low to 11 high

RESULTS AND DISCUSSION

The results of the model tests are presented in charts 1 to 6 and in tables III and IV. Spins to the pilot's right and left were similar, and the data are arbitrarily presented in terms of right spins. Model loading conditions investigated, as indicated in the charts and tables, are listed in table II along with airplane loading conditions. The following techniques are included in the presentation of the data on the charts:

[redacted]

For spins in which a model has a rate of descent in excess of that which can readily be obtained in the tunnel, the rate of descent is recorded as greater than the velocity at the time the model hit the safety net; for example, >300 feet per second, full scale. In such tests, the recoveries are attempted before the model reaches its final steeper attitude and while it is still descending in the tunnel. Such results are considered conservative; that is, recoveries are generally not as fast as when the model is in the final steeper attitude. For recovery attempts in which a model strikes the safety net while it was still in a spin, the recovery is recorded as greater than the number of turns from the time the controls were moved to the time the model struck the net, as >3. A >3 turn recovery, however, does not necessarily indicate an improvement over a >7 turn recovery. When a model recovers without control movement (rudder held with the spin), the results are recorded as "no spin." For recovery attempts for which the model did not recover within 10 turns, the recovery was recorded as ∞.

Erect Spins

Basic design combat gross weight.- Chart 1 presents the results of erect spin and recovery tests made with the model in the basic design combat gross-weight condition $\left(\frac{I_X - I_Y}{mb^2} = -154 \times 10^{-4}\text{; loading 1 in table II}\right)$. The spins with the ailerons either neutral or against the spin were oscillatory, and recoveries attempted by rudder reversal or rudder reversal in conjunction with moving ailerons to full with the spin were unsatisfactory. When the ailerons were preset full with the spin, spins obtained were steep and recoveries by rudder reversal were rapid. Based on the results obtained for the criterion spin (ref. 1), it appears that the recovery characteristics of the airplane for this loading condition would be considered unsatisfactory. Based on results for other loadings and on spin-tunnel experience it appears that this model was quite sensitive to minor variations in aileron deflection and that a steeper-type spin with satisfactory recoveries might also be obtained for this loading when ailerons were neutral or slightly against the spin.

Leading-edge flaps and dive brakes.- Erect spin and recovery tests in the basic design combat gross-weight condition were also made with the leading-edge flaps deflected and with the speed brakes extended. These results indicated no appreciable differences from the results obtained for the clean condition, and are not presented in chart or tabular form.

Mass variations.- The results of tests of the model with a loading representing all wing fuel removed from the basic design combat gross weight $\left(\frac{I_X - I_Y}{mb^2} = -195 \times 10^{-4}\text{; loading 5 in table II}\right)$ are presented in chart 2. These spins were steeper and recoveries were more rapid than for the basic design combat gross-weight loading. Based on the criterion spin, it appears that recoveries from spins of the airplane in this loading by using rudder reversal accompanied by moving ailerons to full with the spin would be satisfactory.

The model was also tested in the revised design combat gross-weight condition $\left(\frac{I_X - I_Y}{mb^2} = -86 \times 10^{-4}\text{; loading 8 in table II}\right)$. The results are presented in chart 3. These results are generally similar to those for the basic design combat gross-weight condition except that, in the criterion setting, two types of spin were observed. Based on slow recoveries obtained from the flatter of these two types of spin, as indicated in the charts, the recovery characteristics of the model in this loading are considered unsatisfactory. From the steeper of these two types of spin, satisfactory recovery characteristics from spins of the airplane by full rudder reversal to against the spin and aileron movement to full with the spin were indicated.

Correlation with full-scale results.- Model results indicate that either a steep spin with satisfactory recoveries or a flat spin with unsatisfactory recoveries may be obtained on the airplane. In flight tests of the airplane conducted to date, only the steeper of the two types of spins has been obtained. No trouble was encountered in obtaining recoveries from these spins.

Reference 1 discusses the influence of such factors as scale effect and tunnel technique in causing differences which occasionally occur between model results and results obtained during the actual airplane spin tests.

Recommended recovery technique for erect spins.- The optimum spin-recovery technique recommended for erect spins of the North American FJ-4 airplane is full rudder reversal accompanied by movement of ailerons to full with the spin. Although, as previously mentioned, flight tests of the airplane to date have indicated only steep spins with satisfactory recoveries, should flat spins be encountered on the airplane, even the optimum technique might not insure satisfactory recovery.

Inverted Spins

The results of the inverted spin and recovery tests of the model are presented in charts 4, 5, and 6. The order used for presenting the data for the inverted spins is different from that used for erect spins. For inverted spins, "controls crossed" for the established spin (right rudder pedal forward and stick to the pilot's left for a spin to the pilot's right) is presented to the right of the chart and "stick back" is presented at the bottom. When the controls are crossed in the established spin, the lateral controls aid the rolling motion; when the controls are together, the lateral controls oppose the rolling motion. The angle ϕ and the longitudinal control position in the chart (and text) are given as up or down relative to the ground.

Accident-test loading condition.- Results of inverted spin tests for a loading condition indicated as representing the accident-test loading condition $\left(\frac{I_X - I_Y}{mb^2} = -201 \times 10^{-4}\text{; loading 6 in table II}\right)$ are presented in chart 4. Good recoveries were obtained by rudder reversal from aileron-neutral spins when the longitudinal controls were maintained at neutral or up, but when the longitudinal controls were full down, recoveries attempted by full rudder reversal were not satisfactory. For spins obtained with the ailerons deflected full with the spin (stick left in an inverted spin turning to the pilot's right) rapid recoveries were also obtained by full rudder reversal. However, for spins obtained with ailerons maintained even slightly against the spin, the recovery characteristics by rudder reversal alone were unsatisfactory. Recoveries obtained by full rudder reversal accompanied by moving ailerons full with the spin were satisfactory, and the results indicated the latter control-manipulation technique to be the optimum for recovery from inverted spins in this loading.

During the inverted spin part of the flight test program of the North American FJ-4 airplane, the spin demonstration article was lost. This was apparently due to high pedal forces encountered in this spin which prevented the pilot from fully reversing the rudder. However, based on an analysis of spin-tunnel results, it appears that if the ailerons are moved to full with the spin in conjunction with rudder movement, it may not be necessary to completely reverse the rudder in order to obtain satisfactory recoveries.

It should be noted that in referring to the direction of turning of airplane inverted spins, the direction specified herein is the direction of the yawing rotation about the Z-body axis of the airplane, as would be indicated on the turn-indicator instrument in the airplane. This yawing rotation is a component of the total spin rotation of the airplane. Reference 3 discusses problems of pilot disorientation in inverted spins, especially those entered inadvertently, a problem which has caused several crashes during recent years.

Accident-test loading condition plus wing-tip rockets.- Chart 5 presents the results of tests made with accident-test loading plus wing-tip rockets which represents the spin-demonstration airplane with no wing fuel and a rocket mounted at each wing tip $\left(\frac{I_X - I_Y}{mb^2} = -153 \times 10^{-4};\right.$ loading 7 in table II$\left.\right)$. The inverted spin pattern for this loading exhibits the same general trend as the results without rockets installed, and the same recovery technique is recommended.

Revised design combat gross-weight condition.- Inverted spin-test results for the revised design combat gross-weight condition $\left(\frac{I_X - I_Y}{mb^2} = -86 \times 10^{-4};\ \text{loading 8 in table II}\right)$ are presented in chart 6. Rapid recoveries were obtained by full rudder reversal from spins with the longitudinal controls neutral or up (relative to the ground). Rudder neutralization appears inadequate for satisfactory recovery.

Landing Condition

Current military specifications require airplanes to be spin-demonstrated in the landing condition from only a one-turn (or incipient) spin, and inasmuch as spin-tunnel test data are obtained for fully developed spins, the landing condition was not investigated on the model. Recovery characteristics in the landing condition may be of significant importance, however, because stall tests of an airplane, generally made at altitude in the landing condition early during the flight test program, may result in an inadvertent spin. Analysis indicates that, although recoveries from fully developed spins may be unsatisfactory (based on the study presented in reference 4 of the results of tests of many models with landing gear and flaps extended and retracted), the FJ-4 airplane should recover satisfactorily from an incipient spin in the landing condition. If a spin is inadvertently entered in the landing condition at any time, the flaps and landing gear should be retracted and recovery attempted immediately.

Spin-Recovery Rocket Tests

The results of tests to evaluate the use of rockets as emergency devices in demonstration spins are presented in table III. The rockets were mounted at the wing tips and were fired to provide either an anti-spin yawing moment or a prospin rolling moment. The thrust of the smallest miniature rockets available exceeded the scaled-down thrust of the rockets indicated as being available for use on the FJ-4 airplane. Therefore, additional tests were made with rockets mounted to provide yawing moment at two-thirds of the wing semispan. The yawing moment thereby obtained was approximately equivalent to that of the full-scale rocket installation. Figure 3 shows the alternate mounting positions for the model rockets. For the tests with the rockets installed, the revised design combat gross-weight condition was represented $\left(\frac{I_X - I_Y}{mb^2} = -86 \times 10^{-4}\text{; loading 8 in table II}\right)$.

Yaw rockets.- Satisfactory recoveries were obtained from the criterion spin by firing rockets mounted either on the outer or inner wing tip and providing approximately 30,000 foot-pounds of antispin yawing moment (full-scale), or mounted at two-thirds of the semispan of the wing (full-scale antispin yawing moment approximately 20,000 foot-pounds). For the latter position, brief tests were made with rockets attached alternately to the upper and lower wing surfaces and indicated no significant aerodynamic effects due to the rocket. Also, this rocket was fired during a spin for which ailerons were set full against and longitudinal controls were neutral, a spin which had a higher rotational rate than the criterion spin. Recoveries from this spin were unsatisfactory, being somewhat slower than from the criterion spin.

Roll rockets.- Rockets mounted to provide approximately 30,000 foot-pounds of prospin rolling moment (full-scale) each were fired at the outer and inner wing tips individually and at both tips simultaneously. The results indicate that satisfactory recoveries were obtained when a total full-scale rolling moment of approximately 60,000 foot-pounds was provided.

Spin-Recovery Parachute Tests

The results of tests made to determine the size of tail parachute required to give satisfactory recoveries of the FJ-4 airplane during emergencies in spin demonstrations are presented in table IV. These tests were conducted for the accident-test loading condition (loading 6 in table II). The towline was attached near the extreme rearward point of the fuselage. (See fig. 1.) The rudder was maintained full with the spin during the recovery attempts. The results indicate that a flat-type stable parachute of 15.2-foot diameter (laid-out-flat) with a drag coefficient of 0.67 (based on laid-out-flat area), shroud lines 20.5 feet long, and a towline 39 feet long should be adequate for recoveries from either erect or inverted spins. Another size stable tail parachute giving equivalent drag could also be used for satisfactory recovery.

SUMMARY OF RESULTS

Based on the results of tests of a 1/28-scale model of the North American FJ-4 airplane, the following summary is considered applicable to the spin and recovery characteristics of the airplane at 30,000 feet:

1. The control movement most conducive to recoveries from all erect spins will be simultaneous full rudder reversal to against the spin and aileron movement to full with the spin (stick full right in a right erect spin). This technique will insure satisfactory recoveries from steep-type spins such as have been encountered on the airplane to date. However, for some conditions of mass distribution in the airplane, this technique may not always be sufficiently effective to insure satisfactory recoveries if a flatter-type developed spin indicated possible by model results is obtained.

2. Deflecting the leading-edge flaps or extending the speed brakes should have little effect on erect spins and recoveries.

3. For inverted spins in a condition similar to the accident-test condition loading, or for such a condition plus wing-tip rockets, satisfactory recoveries should be obtained by simultaneous full rudder reversal and movement of ailerons to full with the spin (controls "together"), with the longitudinal controls maintained at full up with respect to the ground. In the revised design combat gross-weight condition, satisfactory recoveries should be obtained by full rudder reversal.

4. Satisfactory recoveries should be obtained from erect spins by the application of an antispin yawing moment of about 20,000 foot-pounds, full scale. Model results indicated that satisfactory recoveries were possible by application of a prospin rolling moment (rolls right wing down in a right spin) of about 60,000 foot-pounds, full-scale, by rockets attached to the wing tips. The rocket thrust duration should be equivalent to approximately 11 seconds, full scale.

5. A spin-recovery tail parachute of 15.2-foot diameter (laid-out-flat) with a drag coefficient of 0.67, a shroud line length of 20.5 feet, and attached with a 39-foot towline will be adequate to provide satisfactory spin recovery from spin-demonstration flights in an emergency.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., January 13, 1958.

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3. Scher, Stanley H.: Pilot's Loss of Orientation in Inverted Spins. NACA TN 3531, 1955.

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TABLE I.- DIMENSIONAL CHARACTERISTICS OF THE

NORTH AMERICAN FJ-4 AIRPLANE

Overall length, ft	37.68
Wing:	
Span, ft	39.11
Area, sq ft	338.66
Root chord, in.	160.51
Tip chord, in.	47.52
$\bar{c}$, in.	114.42
Leading edge $\bar{c}$ rearward of leading-edge root chord, in.	78.67
Aspect ratio	4.5
Taper ratio	0.30
Sweepback of quarter chord, deg	35
Dihedral, deg	3
Incidence, deg:	
Root	+1
Tip	-3
Airfoil section:	
Root	NACA 64A006 modified
Tip	NACA 64A006 modified
Ailerons:	
Total area, rearward of hinge line, sq ft	30.34
Span, each, percent b/2	36.40
Chord, inboard, in.	30.06
Chord, outboard, in.	21.29
Leading-edge flaps:	
Total area, sq ft	13.98
Span, percent b	76.5
Horizontal tail:	
Span, ft	16.08
Area, sq ft	53.20
Root chord, in.	61.33
Tip chord, in.	18.22
Sweepback of quarter chord, deg	35
Total elevator area, rearward of hinge line, sq ft	12.99
Dihedral, deg	0
Nose to leading edge of horizontal tail at root, ft	29.68
Airfoil section:	
Root	NACA 65A006
Tip	NACA 65A006 modified
Vertical tail:	
Span, fuselage reference line to equivalent tip, ft	8.55
Area, including dorsal, sq ft	9.09
Root chord, in.	76.50
Chord at equivalent tip, in.	20.072
Sweepback of quarter chord, deg	35
Rudder area, rearward of hinge line, sq ft	5.26
Nose to leading edge of vertical tail at root, ft	27.33
Airfoil section:	
Root	NACA 65A006
Tip	NACA 65A006

TABLE II.- MASS CHARACTERISTICS AND INERTIA PARAMETERS FOR THE LOADINGS OF THE NORTH AMERICAN FJ-4 AIRPLANE AND FOR LOADINGS TESTED ON THE 1/28-SCALE MODEL

[Values given are full scale, and moments of inertia are given about the center of gravity]

Loading	Weight, lb	Center-of-gravity location		Relative density, μ, at		Moments of inertia, slug-ft^2			Mass parameters		
		$x/\bar{c}$	$z/\bar{c}$	Sea level	Altitude 30,000 ft	I_X	I_Y	I_Z	$\frac{I_X - I_Y}{mb^2}$	$\frac{I_Y - I_Z}{mb^2}$	$\frac{I_Z - I_X}{mb^2}$
Airplane values											
1 - Basic design combat gross weight, gear up, canopy closed	16,500	0.267	0.104	16.25	43.51	13,038	24,560	35,664	-147×10^{-4}	-142×10^{-4}	289×10^{-4}
2 - Maximum flight design gross weight, gear up, canopy closed	19,369	.250	.110	19.11	51.07	14,923	26,244	38,590	-123	-134	257
3 - Maximum flight design gross weight, gear down, canopy closed	19,369	.254	.119	19.11	51.07	15,583	26,826	39,202	-122	-134	256
4 - Basic design landing gross weight, gear down, canopy open	15,000	.256	.106	14.79	39.55	11,082	24,662	33,054	-190	-118	308
Model values											
1 - Basic design combat gross weight	16,365	0.271	0.086	16.13	43.14	13,373	25,385	35,997	-154×10^{-4}	-137×10^{-4}	291×10^{-4}
5 - Basic design combat less wing fuel	16,944	.243	.079	16.70	44.65	11,125	26,865	35,364	-195	-106	301
6 - Accident-test loading	15,809	.228	.064	15.59	41.68	11,307	26,422	35,110	-201	-116	317
7 - Accident-test loading plus tip rockets	16,094	.242	.071	15.87	42.44	15,474	27,141	39,927	-153	-167	320
8 - Revised design combat gross weight	17,573	.264	.074	17.33	46.35	18,297	25,446	40,633	-86	-182	268

[redacted]

TABLE III.- DATA FOR A SPIN-RECOVERY WING ROCKET OBTAINED WITH THE 1/28-SCALE MODEL OF THE NORTH AMERICAN FJ-4 AIRPLANE

[Model loading 8 in table II. Recovery attempted by firing rockets as indicated; rudder full with the spin; right erect spins]

Location of rockets	Elevator	Ailerons	α, deg	φ, deg (a)	V, ft/sec (b)	Ω, radian/sec (b)	Force, lb (b)	Yawing (or rolling) moment, ft-lb (b)	Yawing-moment coefficient, C_n	Turns for recovery
Yaw (Antispin)										
Outer wing tip (left wing tip)	2/3 up	1/3 against	(c)	(c)	[d]333 371	(c)	1,539	30,095	[d,e]0.0461 .0371	[f]$\frac{1}{4}$, [g]$\frac{1}{4}$, [h]$\frac{1}{4}$, [i]$\frac{1}{2}$
Inner wing tip (right wing tip)	2/3 up	1/3 against	(c)	(c)	(c)	(c)	1,539	30,095	(c)	[i]$\frac{1}{4}$, [i]$\frac{1}{4}$, [i]$\frac{1}{4}$
Outer wing (left wing panel), upper wing surface at 2/3 semispan	2/3 up	1/3 against	[d]39 92	[d]33U 41D	[d]317 356	0.36	1,539	20,062	[d,e]0.0339 .0269	[k]$\frac{3}{4}$, [h]1, [l]1
Outer wing (left wing panel), upper wing surface at 2/3 semispan	Neutral	Full against	[d]42 97	[d]46U 36D	[d]333 371	0.41	1,539	20,062	[d,e]0.0307 .0248	[h]2, [h]$2\frac{1}{2}$, [h]$2\frac{1}{2}$
Outer wing (left wing panel), lower wing surface at 2/3 semispan	2/3 up	1/3 against	[d]49 77	[d]22U 22D	[d]317 349	0.39	1,539	20,062	[d,e]0.0339 .0280	[h]$\frac{1}{2}$, [h]1
Roll (Prospin)										
Outer wing tip (left wing tip)	2/3 up	1/3 against	(c)	(c)	(c)	(c)	1,539	30,095	(c)	>4
Outer and inner wing tip (left and right wing tip)	2/3 up	1/3 against	(c)	(c)	(c)	(c)	3,078	60,190	(c)	[m]1, [m]1
Inner wing tip (right wing tip)	2/3 up	1/3 against	(c)	(c)	(c)	(c)	1,539	30,095	(c)	[n]$\frac{3}{4}$, >2

[a]U inner wing up; D inner wing down.
[b]Model values converted to corresponding full-scale values.
[c]Not available.
[d]Oscillatory spin, range of values given.
[e]Coefficients correspond with range of rates of descent indicated.
[f]Model entered a short glide.
[g]Model entered a glide followed by an aileron roll.
[h]Model entered a dive.
[i]Model entered a glide followed by a left spin.
[j]Model entered a glide followed by left turn.
[k]Model entered an inverted dive.
[l]Model entered a dive followed by a left spin.
[m]Due to rocket thrust, model entered a roll.
[n]Model entered a wide spiral.

TABLE IV.- DATA FOR A SPIN-RECOVERY TAIL PARACHUTE OBTAINED WITH THE 1/28-SCALE MODEL OF THE NORTH AMERICAN FJ-4 AIRPLANE

[Model loading 6 in table II. Recovery attempted by opening tail parachute; spins to pilot's right, clean condition. Model values have been converted to corresponding full-scale values.]

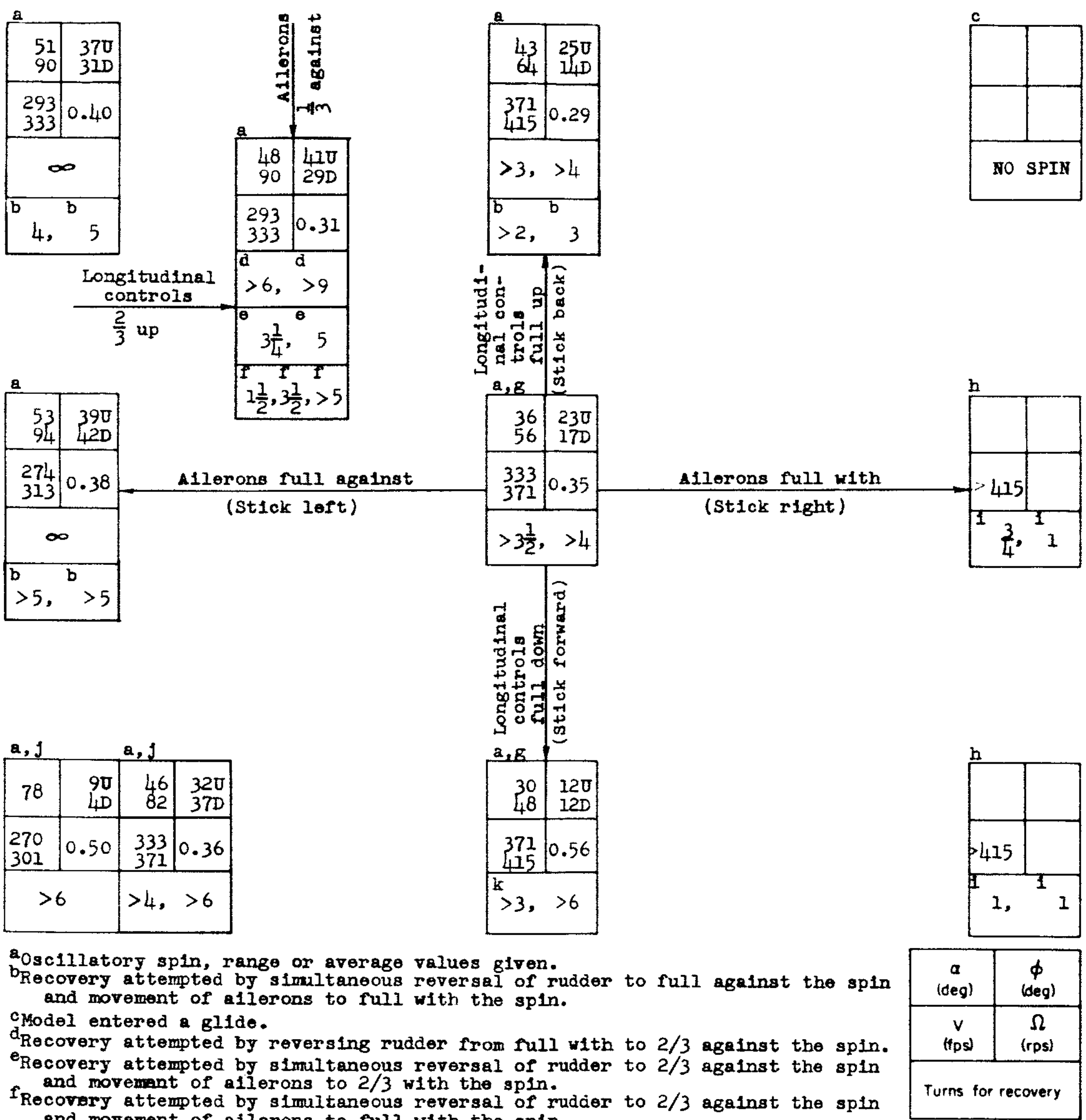
Parachute diameter, ft	Towline length, ft	Approximate parachute drag coefficient	Rudder	Ailerons	Longitudinal controls	Turns for recovery
			Erect Spins			
9.33	39.11	0.63	Full with	1/3 against	2/3 up	$1\frac{1}{2}$, 2, $2\frac{1}{2}$, $2\frac{3}{4}$, >3
10.5	39.11	.60	Full with	1/3 against	2/3 up	1, $1\frac{1}{2}$, 2, $2\frac{1}{2}$, $3\frac{1}{4}$
11.67	39.11	.59	Full with	1/3 against	2/3 up	$1\frac{1}{4}$, 2, $2\frac{1}{4}$, >$2\frac{1}{2}$, $2\frac{3}{4}$
12.83	39.11	.59	Full wigh	1/3 against	2/3 up	$1\frac{1}{2}$, 2, $2\frac{1}{4}$, >$2\frac{1}{2}$, >$2\frac{3}{4}$
14.0	39.11	.62	Full with	1/3 against	2/3 up	$1\frac{1}{4}$, $1\frac{3}{4}$, 2, >2, >3
15.17	39.11	.67	Full with	1/3 against	2/3 up	$\frac{3}{4}$, $1\frac{1}{4}$, $1\frac{1}{2}$, 2, $2\frac{1}{4}$
			Inverted Spins			
7.0	39.11	0.54	Full with	1/3 against	2/3 up	$2\frac{1}{4}$, $2\frac{1}{2}$, >$3\frac{1}{2}$, 4, >6
8.17	39.11	.55	Full with	1/3 against	2/3 up	$1\frac{1}{2}$, 3, 3, $3\frac{1}{4}$, >4
9.33	39.11	.63	Full with	1/3 against	2/3 up	1, $1\frac{1}{4}$, $1\frac{1}{2}$, $1\frac{1}{2}$, $3\frac{1}{4}$
10.5	39.11	.60	Full with	1/3 against	2/3 up	$\frac{3}{4}$, 2, $2\frac{1}{2}$, >3, >$4\frac{1}{2}$
10.5	19.56	.60	Full with	1/3 against	2/3 up	$1\frac{1}{4}$, >2, $2\frac{1}{4}$, $2\frac{1}{2}$, $4\frac{1}{2}$
10.5	39.11	.60	Full with	Full against	Full up	$\frac{1}{2}$, $\frac{3}{4}$, 1, $2\frac{1}{4}$, $3\frac{1}{4}$
11.67	39.11	.59	Full with	1/3 against	2/3 up	$\frac{1}{2}$, $\frac{3}{4}$, 1, $1\frac{1}{4}$, $1\frac{1}{2}$
11.67	19.56	.59	Full with	1/3 against	2/3 up	$\frac{1}{4}$, $\frac{1}{2}$, >$\frac{1}{2}$, $\frac{3}{4}$, 1
11.67	19.56	.59	Full with	Full against	Full up	$\frac{1}{4}$, $\frac{1}{2}$, 1, $1\frac{1}{2}$, 2
14.0	39.11	.62	Full with	1/3 against	2/3 up	$\frac{1}{4}$, $\frac{1}{4}$, $\frac{1}{4}$, $\frac{1}{4}$, $\frac{1}{2}$

CHART 1.— SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

[Recovery attempted by rapid reversal of rudder to full against the spin except as indicated (recovery attempted from, and steady-spin data presented for, rudder-full-with spins)]

Airplane	Attitude	Direction	Loading (see table II.) 1	
FJ-4	Erect	Right	Basic design combat gross weight	
Leading-edge flaps undeflected			Center-of-gravity position 27.1 percent $\bar{c}$	Altitude 30,000 ft

Model values converted to full scale U–inner wing up D–inner wing down



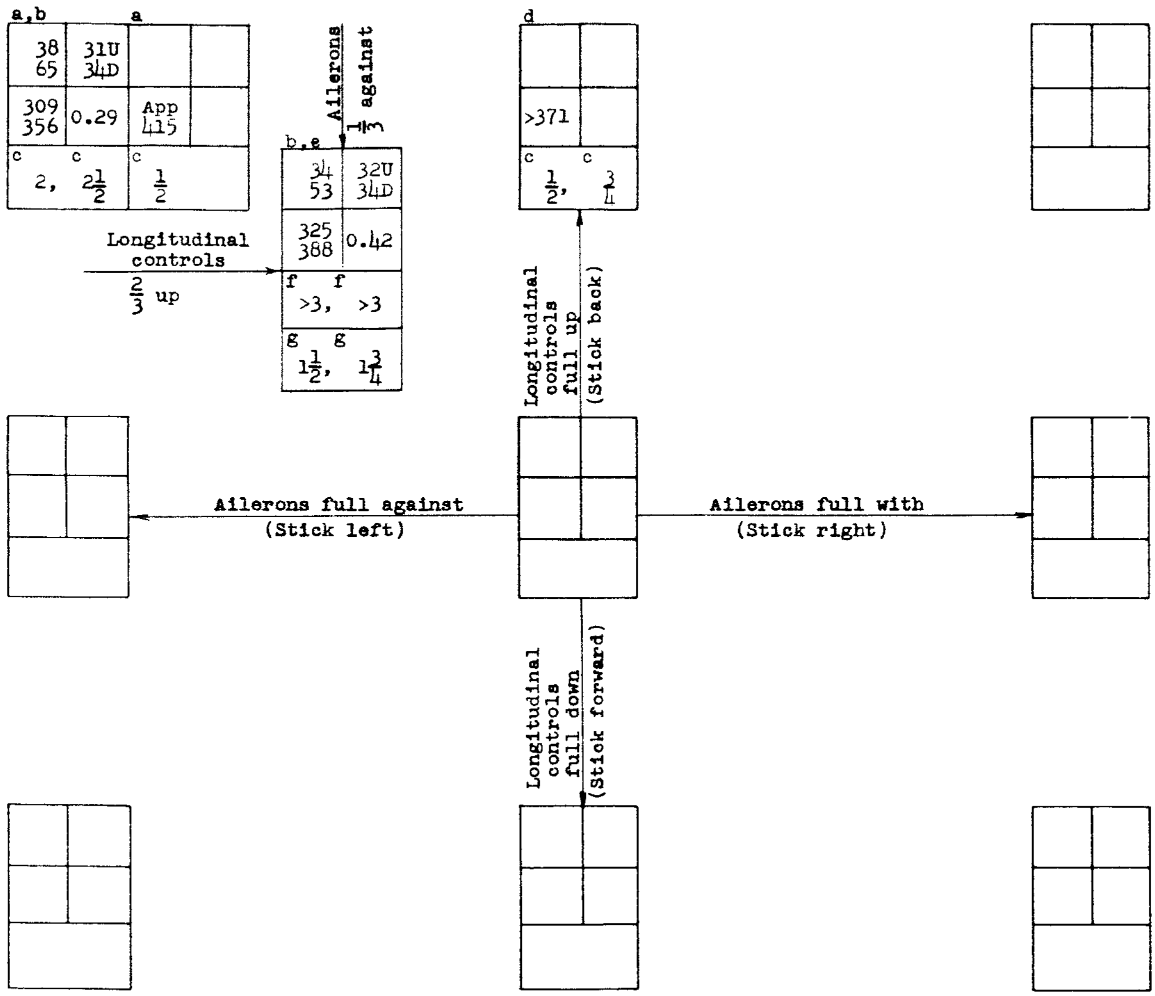
[a]Oscillatory spin, range or average values given.
[b]Recovery attempted by simultaneous reversal of rudder to full against the spin and movement of ailerons to full with the spin.
[c]Model entered a glide.
[d]Recovery attempted by reversing rudder from full with to 2/3 against the spin.
[e]Recovery attempted by simultaneous reversal of rudder to 2/3 against the spin and movement of ailerons to 2/3 with the spin.
[f]Recovery attempted by simultaneous reversal of rudder to 2/3 against the spin and movement of ailerons to full with the spin.
[g]Wandering spin.
[h]Steep spin; recovery attempted before final attitude attained.
[i]Recovered in an aileron roll.
[j]Two conditions possible.
[k]Visual estimate.

CHART 2.—SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

[Recovery attempted as indicated (recovery attempted from, and steady-spin data presented for, rudder-full-with spins)]

Airplane	Attitude	Direction	Loading (see table II) 5	
FJ-4	Erect	Right	Basic design combat less wing fuel	
Leading-edge flaps undeflected		Center-of-gravity position 24.3 percent $\bar{c}$	Altitude 30,000 ft	

Model values converted to full scale U–inner wing up D–inner wing down



[a]Two conditions possible.
[b]Oscillatory spin, range of values given.
[c]Recovery attempted by simultaneous reversal of rudder to full against the spin and movement of ailerons to full with the spin.
[d]Steep spin; recovery attempted before final attitude attained.
[e]Wandering spin.
[f]Recovery attempted by reversing rudder from full with to 2/3 against the spin.
[g]Recovery attempted by simultaneous reversal of rudder to 2/3 against the spin and movement of ailerons to 2/3 with the spin.

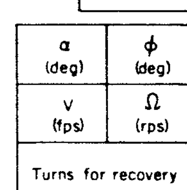
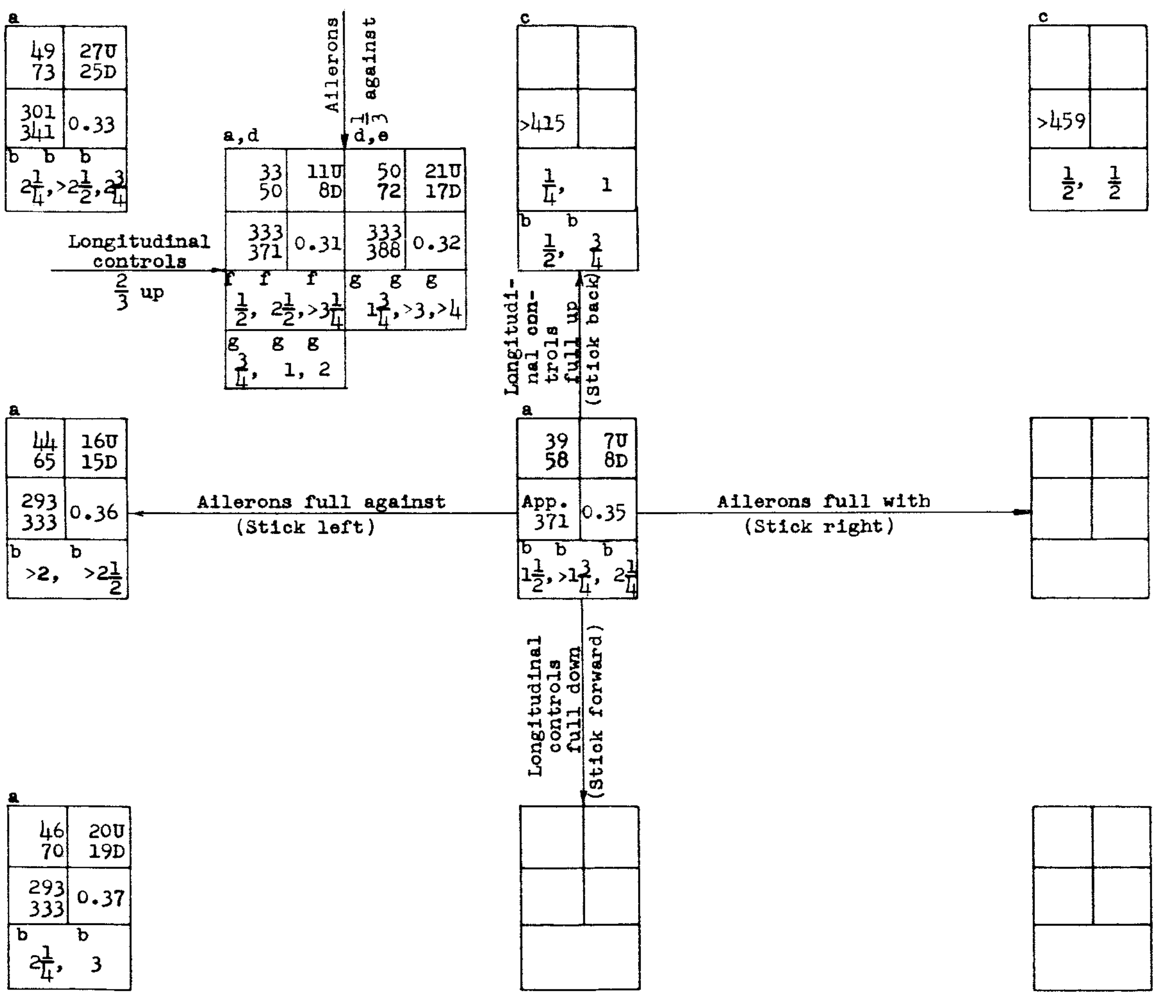


CHART 3.—SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

[Recovery attempted by rapid reversal of rudder to full against the spin except as indicated (recovery attempted from, and steady-spin data presented for, rudder-full-with spins)]

Airplane	Attitude	Direction	Loading (see table II) 8
FJ-4	Erect	Right	Revised design combat gross weight
Leading-edge flaps undeflected		Center-of-gravity position 26.4 percent $\bar{c}$	Altitude 30,000 ft

Model values converted to full scale U—inner wing up D—inner wing down



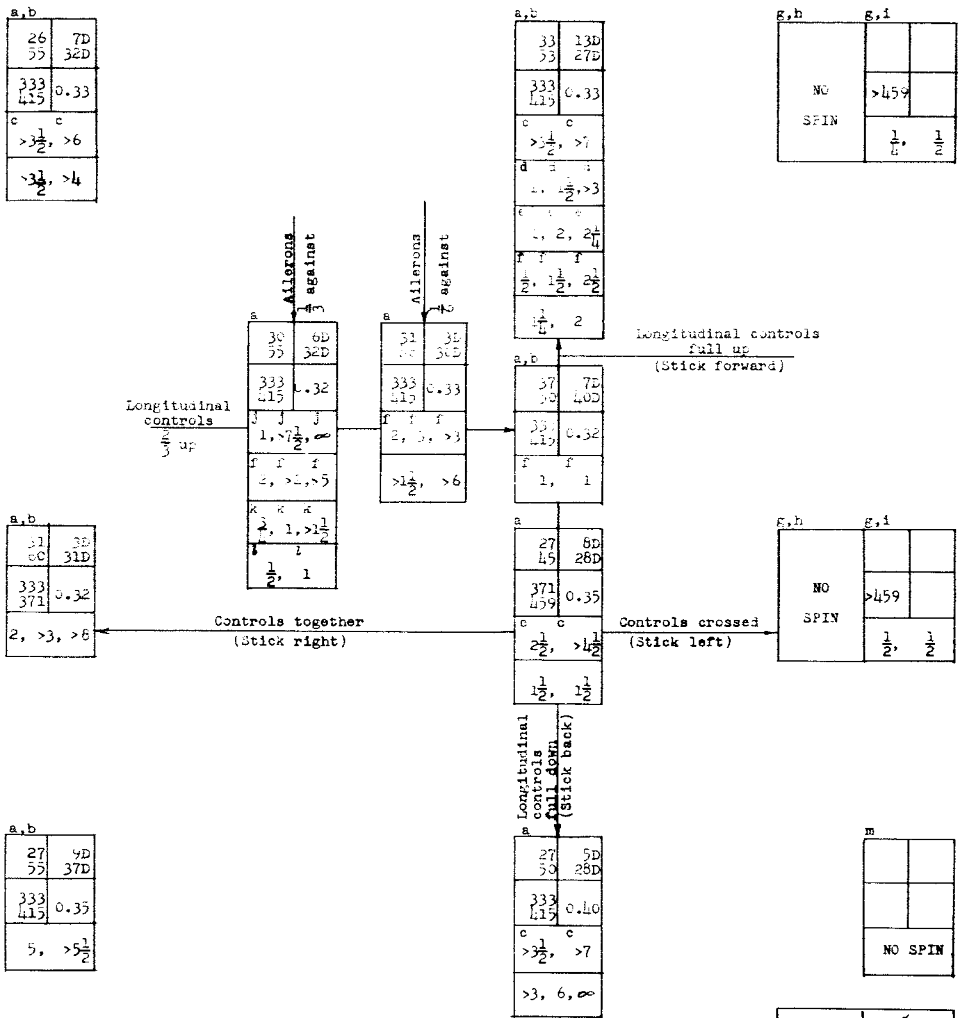
α (deg)	ϕ (deg)
V (fps)	Ω (rps)
Turns for recovery	

[a]Oscillatory and wandering spin, range or average values given.
[b]Recovery attempted by simultaneous reversal of rudder to full against the spin and movement of ailerons to full with the spin.
[c]Steep spin, recovery attempted before final attitude attained.
[d]Two conditions possible.
[e]Oscillatory spin, range of values given.
[f]Recovery attempted by reversing rudder from full with to 2/3 against the spin.
[g]Recovery attempted by simultaneous reversal of rudder to 2/3 against the spin and movement of ailerons to 2/3 with the spin.

TABLE [illegible] INVERTED SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

[Recovery attempted by rapid reversal of rudder to full against the spin except as indicated (recovery attempted from, and steady-spin data presented for, rudder-full-with spins)]

Airplane FJ-4	Attitude Inverted	Direction Pilot's right	Loading (see table II) 6. Accident test loading	
Leading-edge flaps undeflected		Altitude 30,000 ft	Center-of-gravity position 32.8 percent $\bar{c}$	



α (deg)	ϕ (deg)
V (fps)	Ω (rps)
Turns for recovery	

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

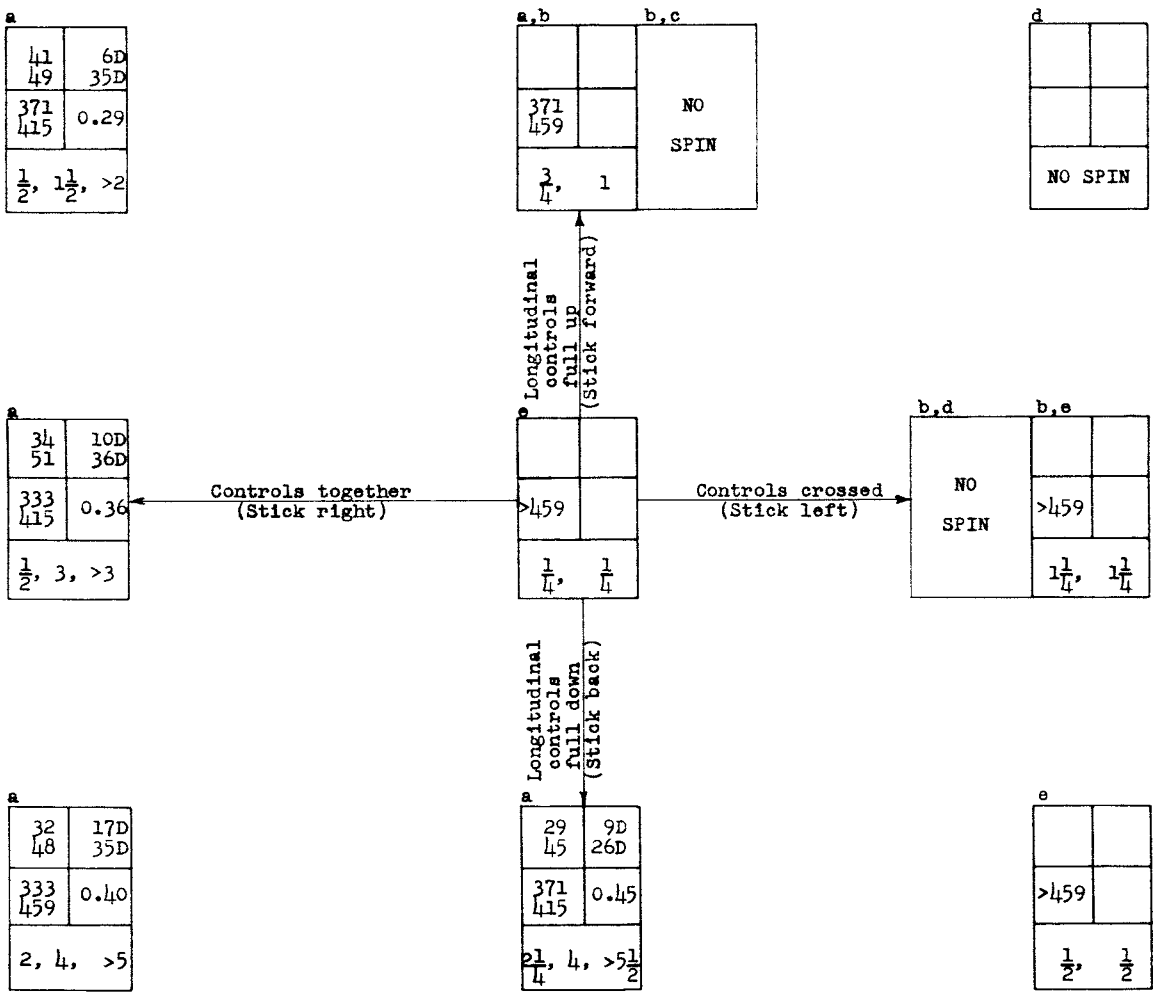
[a]Oscillatory spin, range of values given.
[b]Wandering spin.
[c]Recovery attempted by rudder neutralization.
[d]Recovery attempted by reversing rudder from full with to 1/3 against the spin.
[e]Recovery attempted by reversing rudder from full with to 1/2 against the spin.
[f]Recovery attempted by reversing rudder from full with to 2/3 against the spin.
[g]Two conditions possible.
[h]Model entered a short inverted dive followed by an aileron roll.
[i]Steep spin; recovery attempted before final attitude attained.
[j]Recovery attempted by moving ailerons from 1/3 against to 2/3 with the spin.
[k]Recovery attempted by simultaneous rudder neutralization and movement of ailerons to 2/3 with the spin.
[l]Recovery attempted by simultaneous reversal of rudder to 2/3 against the spin and movement of ailerons to 2/3 with the spin.
[m]Model entered an aileron roll.

CHART 5.- INVERTED SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

[Recovery attempted by rapid reversal of rudder to full against the spin (recovery attempted from, and steady-spin data presented for, rudder-full-with spins)]

Airplane	Attitude	Direction	Loading (see table II)
FJ-4	Inverted	Pilot's right	Accident test loading plus tip rockets
Leading-edge flaps undeflected		Center-of-gravity position 24.2 percent $\bar{c}$	Altitude 30,000 ft

Model values converted to full scale   U–inner wing up   D–inner wing down



[a]Oscillatory and wandering spin, range of values given.
[b]Two conditions possible.
[c]Model entered a vertical dive.
[d]Model entered an inverted dive.
[e]Steep spin; recovery attempted before final attitude attained.

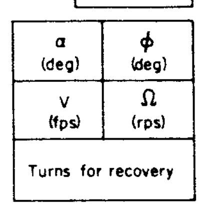


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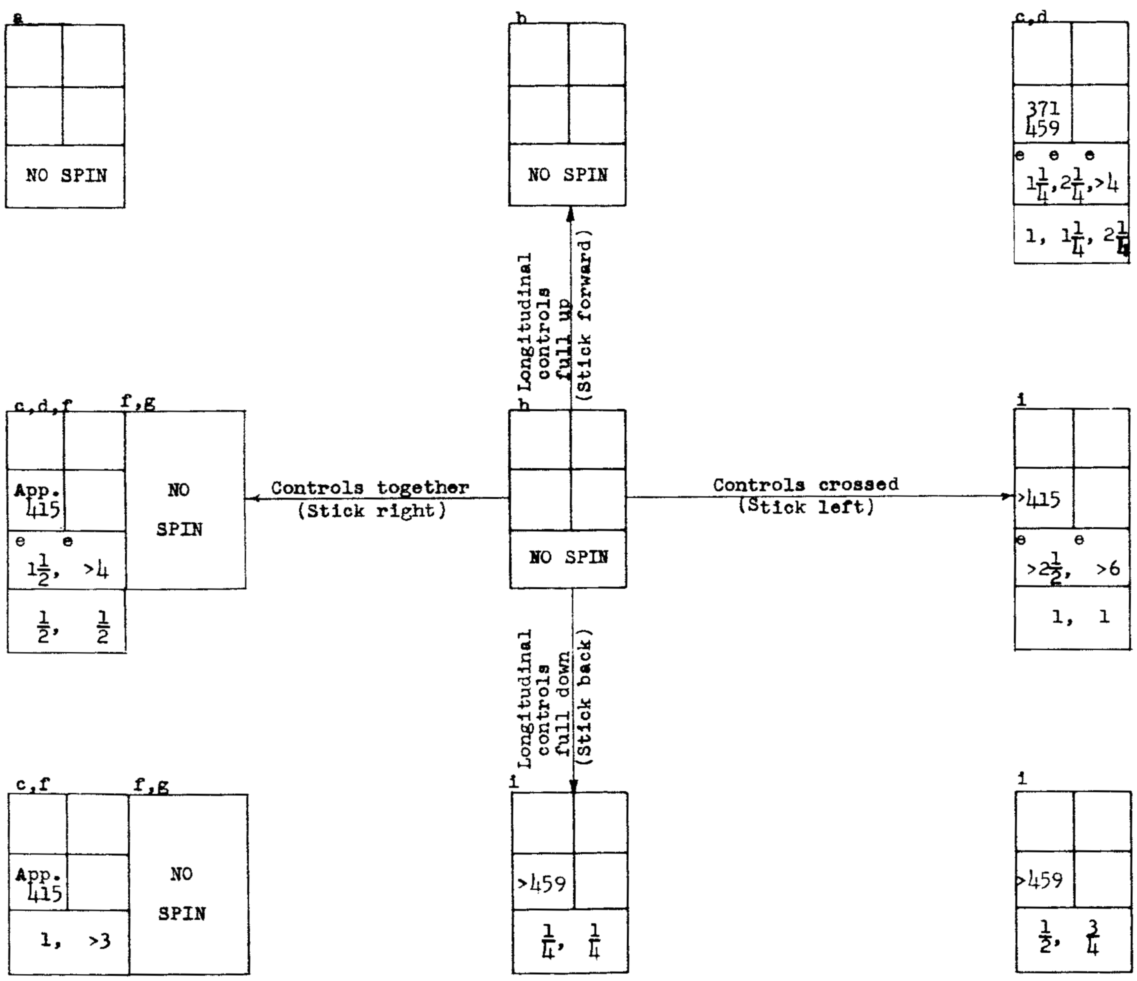
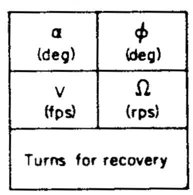
CHART 6.- INVERTED SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

[Recovery attempted by rapid reversal of rudder to full against the spin except as indicated (recovery attempted from, and steady-spin data presented for, rudder-full-with spins)]

Airplane	Attitude	Direction	Loading (see table II) S
FJ-4	Inverted	Pilot's right	Revised design combat gross weight
Leading-edge flaps undeflected		Center-of-gravity position 26.4 percent $\bar{c}$	Altitude 30,000 ft

Model values converted to full scale U–inner wing up D–inner wing down





[a]Model entered a spin to the pilot's left.
[b]Model entered an inverted dive.
[c]Oscillatory spin, range of values given.
[d]Whipping and wandering spin.
[e]Recovery attempted by rudder neutralization.
[f]Two conditions possible.
[g]Model entered an erect dive.
[h]Model entered a vertical dive.
[i]Steep spin; recovery attempted before final attitude attained.

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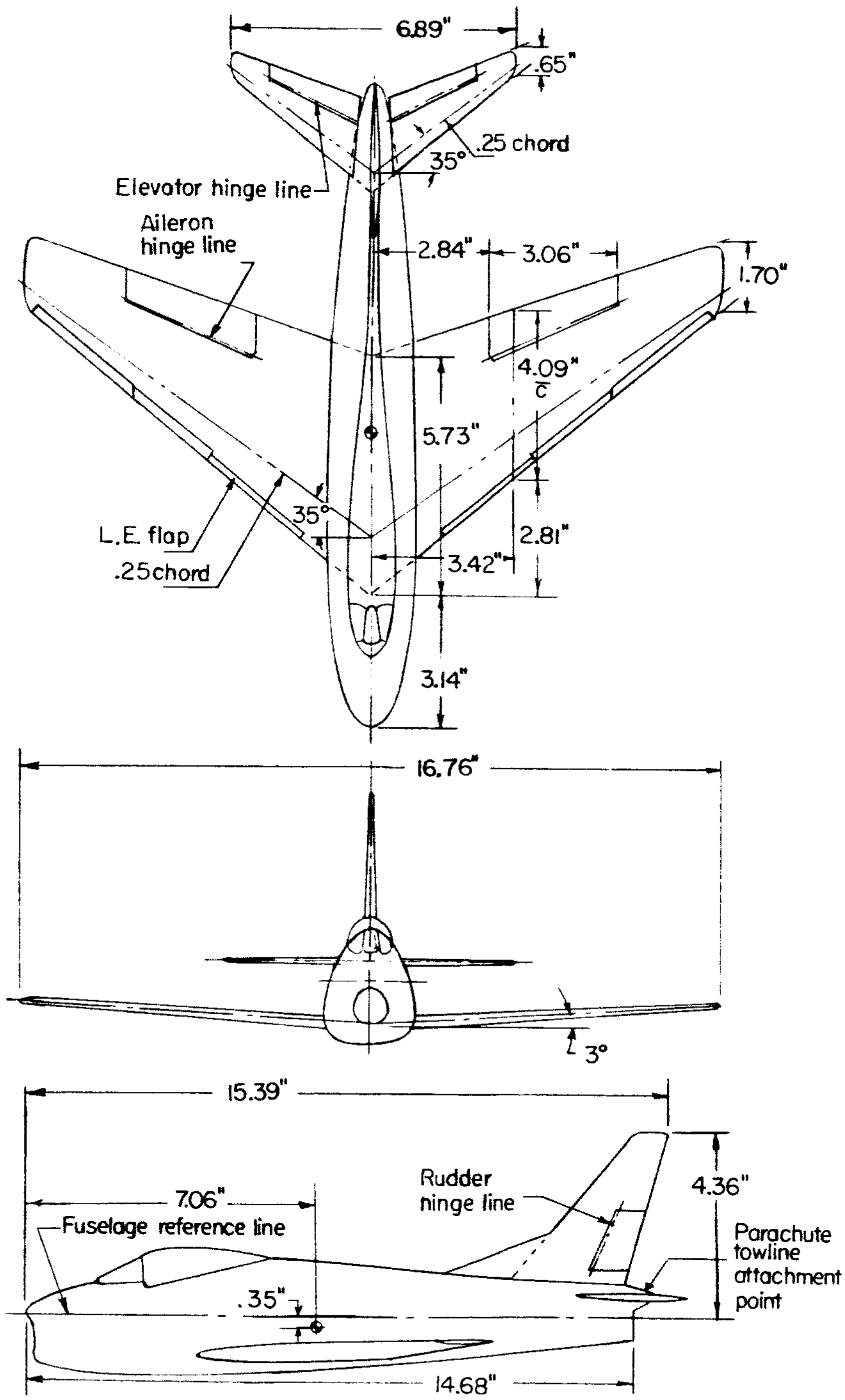

Figure 1.- Three-view drawing of the 1/28-scale model of the North American FJ-4 airplane. Center-of-gravity position indicated is for the basic design combat gross-weight loading.

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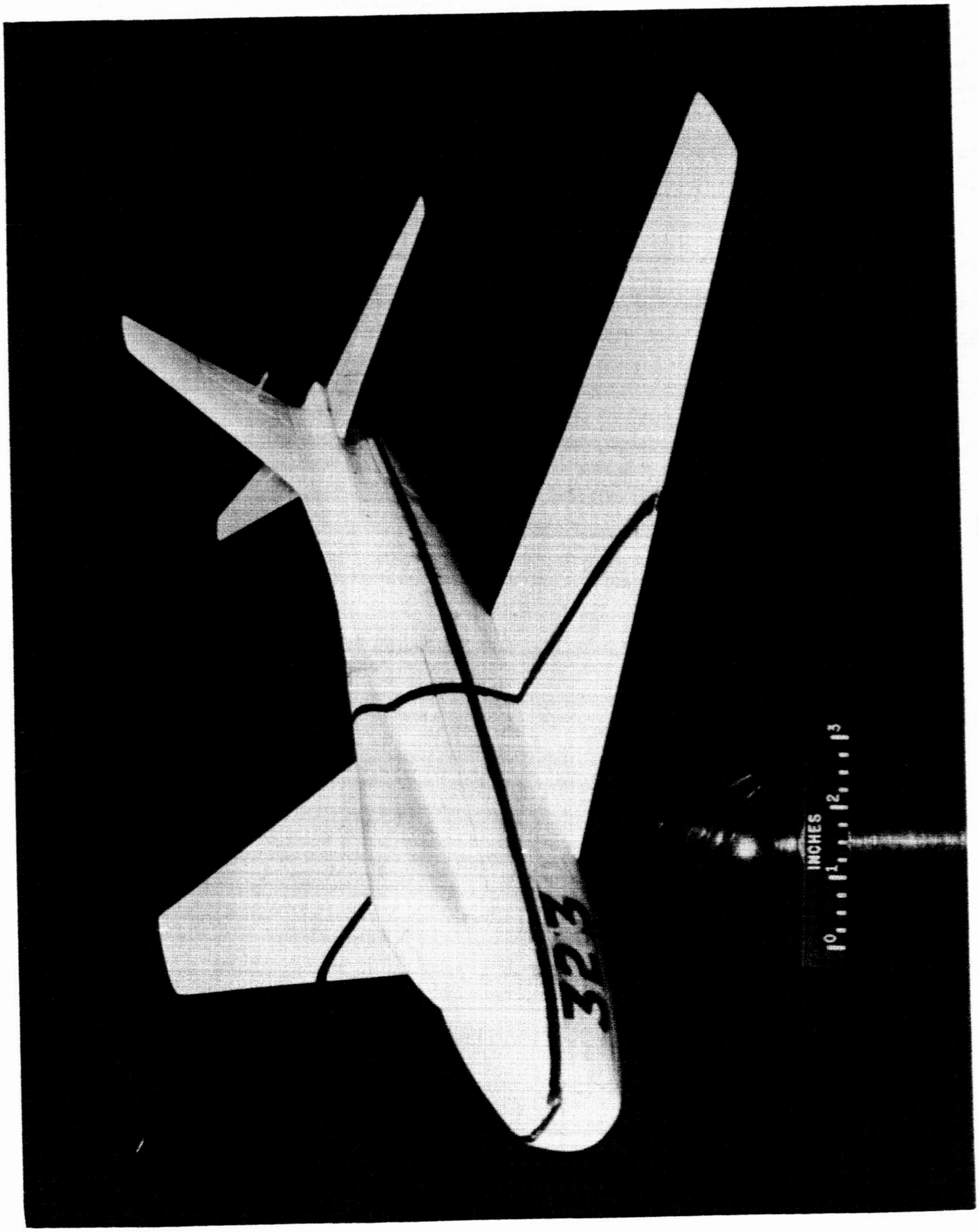

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Figure 2.- Photograph of the 1/28-scale model of the North American FJ-4 airplane in the clean condition.

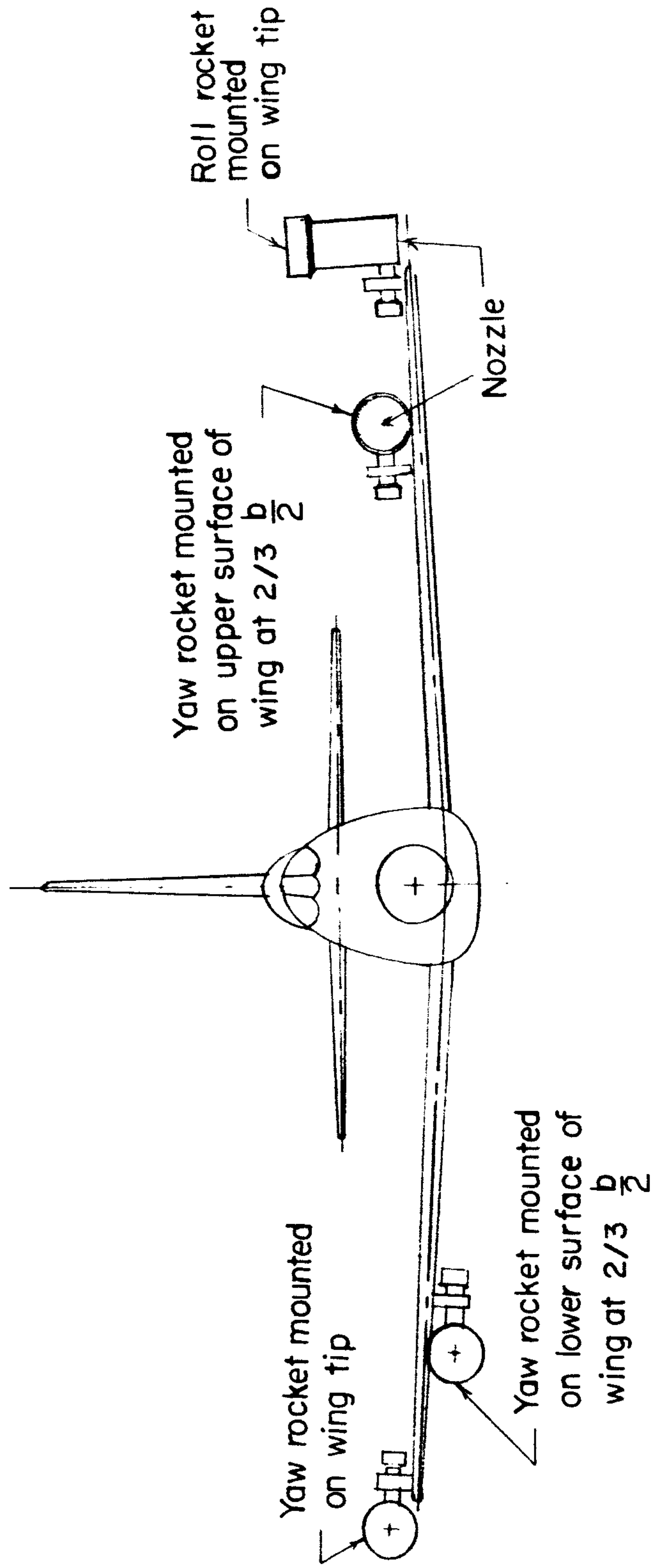

Figure 3.- Sketch indicating alternate positions used for mounting model rockets during tests.

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FREE-SPINNING-TUNNEL INVESTIGATION OF A 1/28-SCALE MODEL OF THE NORTH AMERICAN FJ-4 AIRPLANE

TED NO. NACA AD-3112

By Frederick M. Healy

ABSTRACT

Results of an investigation of a dynamic model in the Langley 20-foot free-spinning tunnel are presented. Both erect and inverted spins were investigated for various conditions of mass distribution, and recovery from spins obtained was attempted by various control manipulations. Tests were made of the effects of deflecting leading-edge flaps or of extending speed brakes. The sizes of wing-tip rockets or tail parachute required for spin recovery in an emergency were determined.

INDEX HEADINGS

Airplanes - Specific Types	1.7.1.2
Spinning	1.8.3
Mass and Gyroscopic Problems	1.8.6
Parachutes	1.10
Piloting Techniques	7.7

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NACA RM SL58A29 [redacted]

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OF THE NORTH AMERICAN FJ-4 AIRPLANE

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